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None

(58) Field of search
G2A

(54) Controlled light emission

(57) In a step-and-repeat process for xposing a wafer 2 to light through a mask 11, using light from a short-arc mercury-vapour lamp 1 in a continuously lit state, exposure being effected while the power consumption of the lamp is at a high level with shutter 4 open and shifting of wafer 2 being effected while the power consumption of the lamp is at a low lev l with shutter 4 closed, the high level power consumption of the lamp is gradually increased to compensate for a gradually reducing light output. The increase may be effected on the basis of experience or by using a photosensor.

FIG. 1

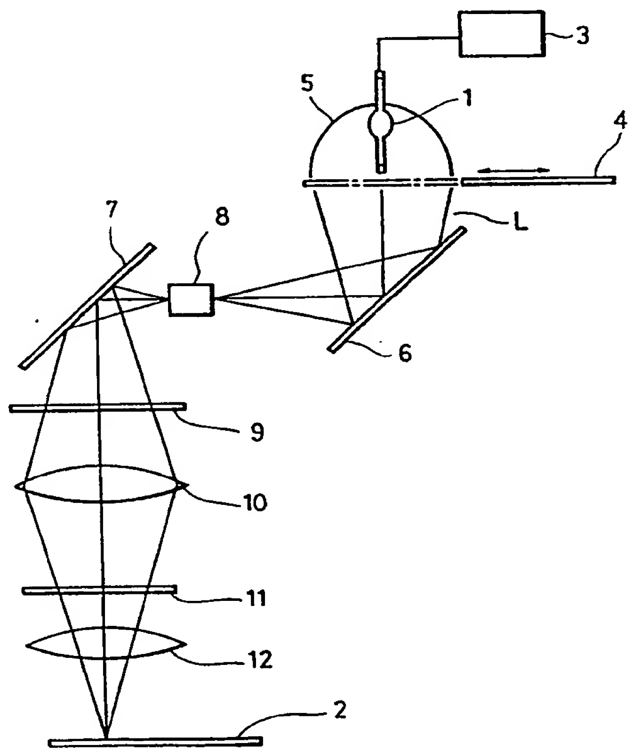

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FIG. 1

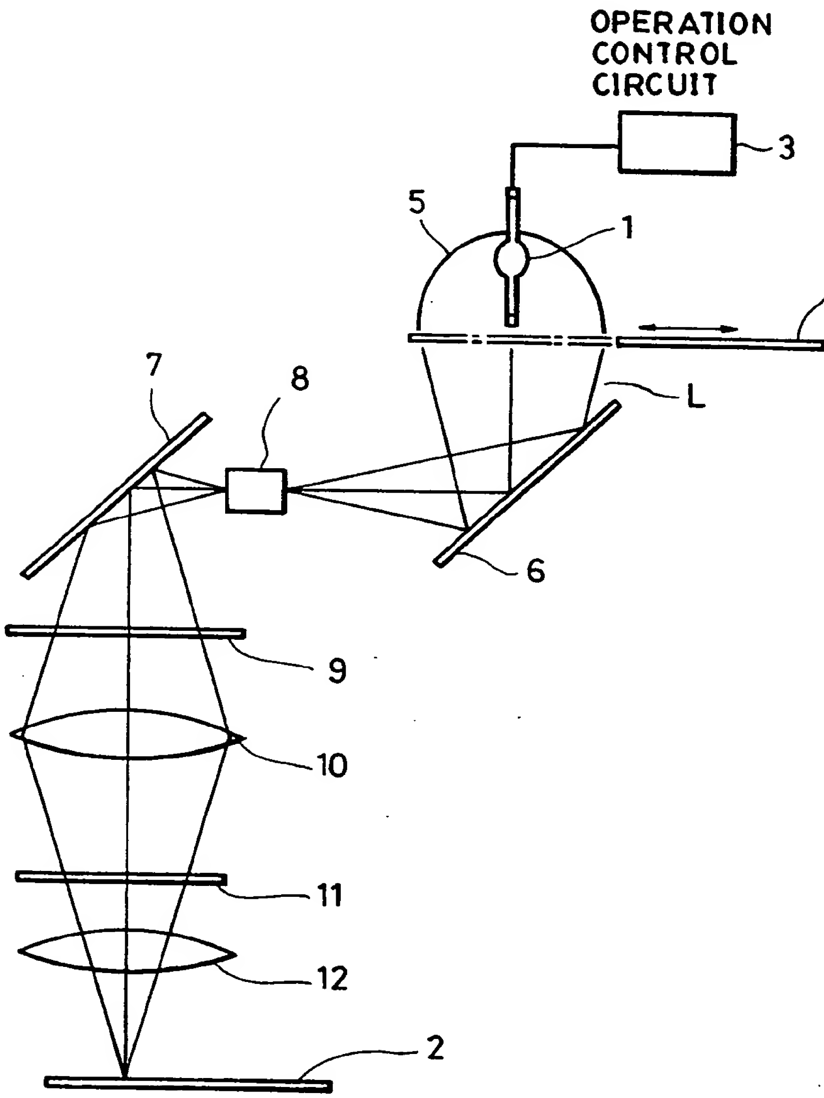


FIG. 2

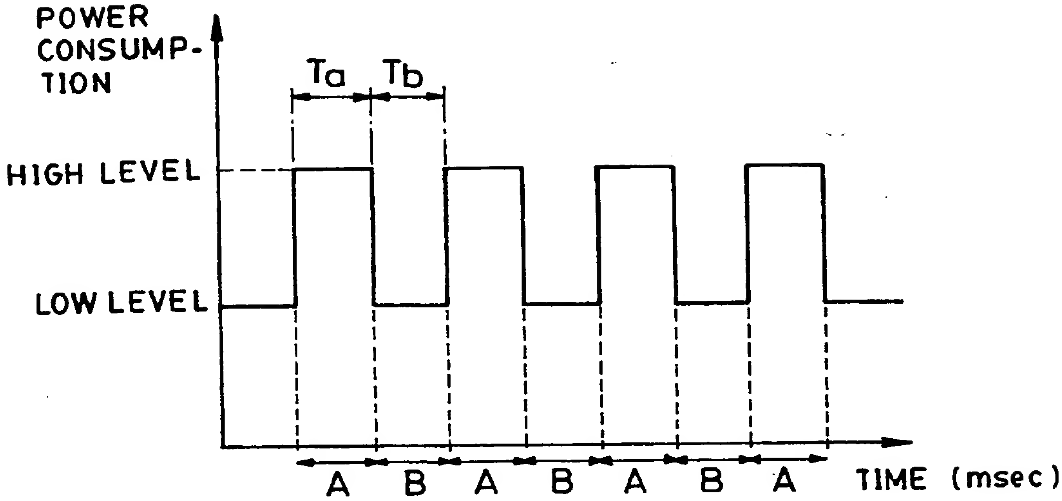

POWER CONSUMPTION
Ta
Tb
HIGH LEVEL
LOW LEVEL
A
B
A
B
A
B
A
TIME (msec)

FIG. 3

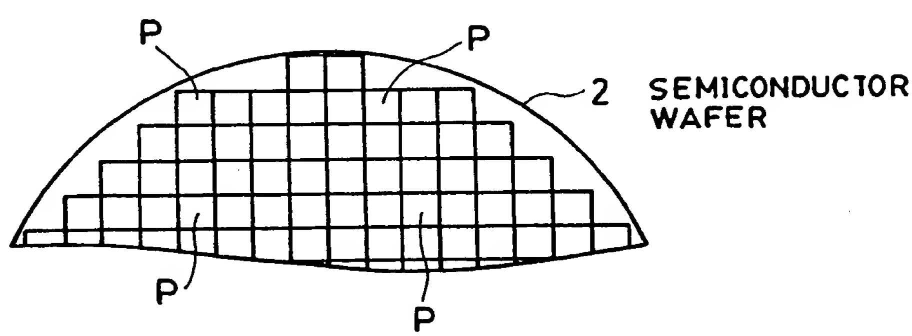
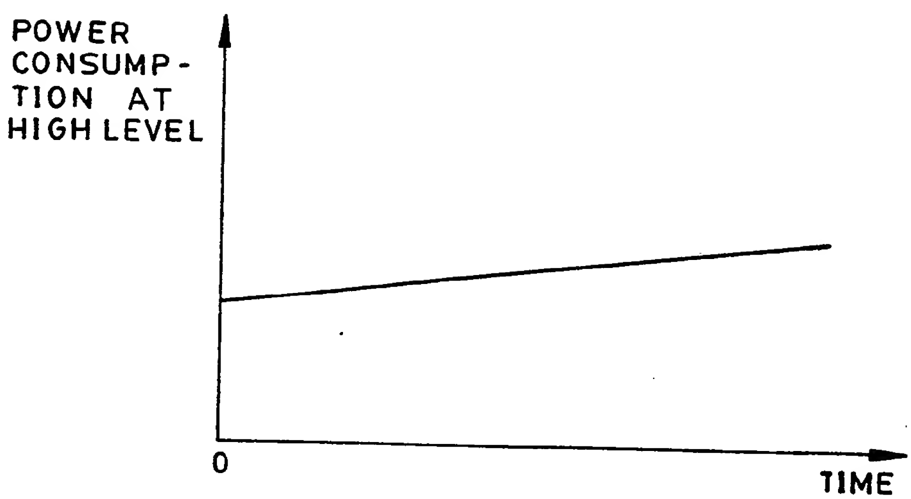

P
P
2
SEMICONDUCTOR WAFER
P
P

FIG. 4



SPECIFICATION

Method of exposing a semiconductor wafer to light from a mercury-vapor lamp

This invention relates to a method of exposing a semiconductor wafer to light from a mercury-vapor lamp.

Upon fabrication of a semiconductor device such as an integrated circuit, large-scale integrated circuit, super large-scale integrated circuit or the like, a photofabrication process is carried out. For example, in order to remove portions of a silicon oxide film formed on a surface of a substrate, which is for example a silicon wafer, a photofabrication process is carried out in accordance with an image pattern such as a circuit pattern. This photofabrication process includes such steps that a photoresist film is formed over the silicon oxide film on the silicon substrate and the photoresist film is then exposed to ultraviolet rays through a photomask having a pattern image. After exposure, the photoresist film is developed and the silicon oxide film is then subjected to an etching treatment. Thereafter, a circuit-forming treatment such as diffusion, ion implantation or the like is applied to the silicon substrate through the thus-etched silicon oxide film.

A semiconductor wafer is generally circular with its surface area supposed to be divided into minute square sections arranged in rows and columns. These minute sections will each be cut afterwards to form chips which will be semiconductor devices respectively. A sheet of semiconductor wafer is generally 3 inches, 5 inches or 6 inches across. The sizes of such semiconductor wafers tend to increase, coupled with progresses in their fabrication technology.

A high out-put mercury-vapor lamp is virtually indispensable in order to expose the entire surface of a semiconductor wafer simultaneously so that all the minute sections, which will individually be formed into chips, are printed at once. Use of such a high-output mercury-vapor lamp is however accompanied by such problems that it renders an exposure system in which the lamp assembly is large and a considerably high degree of technique is required for the uniformity of illuminance on the surface of the semiconductor wafer. Consequently, it is very difficult to meet the tendency of enlargement of semiconductor wafers practically.

With the foregoing in view, it has recently been proposed to expose minute sections, which are arranged in rows and columns on a semiconductor wafer, one after another successively so that pattern images are printed successively and respectively on the minute sections. In such a stepwise exposure method, it is the practice to expose an area equivalent to only one of the minute sections in each exposure operation. Therefore, the stepwise exposure method permits the use of a low-output mercury-lamp, thereby bringing about such substantial advantages that an exposure system employed would have been reduced in size and the illuminance can be readily made uniform on the surface of each semiconductor wafer because the area of each exposure is small. As a result, a pattern image can be printed with a high degree of accuracy.

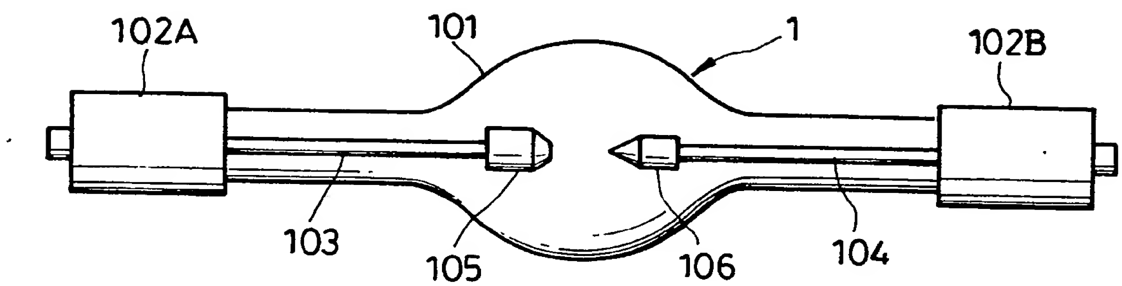
A mercury-vapor lamp cannot however be repeatedly turned on and off in a short cycle because the enclosed mercury vapor undergoes condensation while the lamp is turned off. It is therefore advantageous to cause a mercury-vapor lamp to light repeatedly and alternately at a low power consumption level and at a high power consumption level while maintaining the mercury-vapor lamp in a continuously-lit state, to expose a minute section of a semiconductor wafer, which minute section has assumed an exposure position, to the light from the mercury-vapor lamp when the mercury-vapor lamp is lit at the high power consumption level, and when the mercury-vapor lamp is lit at the low power consumption level, to shift the semiconductor wafer semiconductor wafer, which another minute section is to be subjected to next exposure, is allowed to assume the exposure position, while the light from the mercury-vapor lamp is cut off by means of a shutter. The above method can provide a required level of light quantity at the high power consumption level and at the same time, keeps the mercury-vapor lamp in its lit state at the low power consumption level while avoiding wasting of electric power.

In such a stepwise exposure method, the light of the mercury-vapor lamp is not utilized while the shutter is closed, resulting in such drawbacks that a lot of electricity is still wasted and the shutter is susceptible to considerable damage due to its exposure to the high-energy light. The shutter is required to operate quick, because if its opening or closing motion should be slow, non-uniform exposure of a semiconductor wafer due to such a slow opening or closing motion of the shutter becomes a problem. In order to meet this requirement, it is indispensable that the shutter has a light weight. However, a light-weight shutter will inevitably result in poor heat resistance. As a result, such a light-weight shutter tends to undergo deformation due to heat which is built up while shielding the light and hence to develop a malfunction which impairs its smooth opening and closing operation.

With the foregoing in view, it may be contemplated to light, during each closure period of the shutter, the mercury-vapor lamp with a power consumption smaller than its power consumption during the exposur time, i.e., while the shutter is kept open.

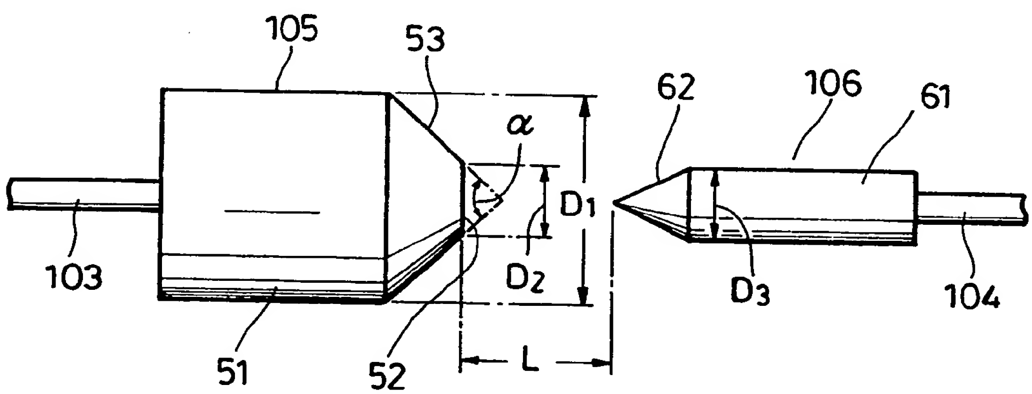
Such an exposure method has however been found to involve a new problem. Namely, when the power consumption of the mercury-vapor lamp is varied at a short time interval to conduct the exposure treatment of the semiconductor wafer at a high speed while keeping the mercury-vapor lamp lit continuously, its electrodes are subjected to severe wear and the quantity of light radiated from the mercury-

FIG. 5



102A
101
1
102B
103
105
106
104

FIG. 6



105
53
62
106
61
α
D1
D2
D3
103
104
51
52
L

vapor lamp is thus gradually reduced with the passage of the lit time of the mercury-vapor lamp. Moreover, the service life of the mercury-vapor lamp becomes shorter. As a result, it is not possible to carry out stable exposure continuously at the initial degree of exposure over a long period of time.

With the foregoing in view, the present invention has as its object the provision of a method for exposing a semiconductor wafer by a mercury-vapor lamp, in which method the wearing of the electrodes of exposure method of a semiconductor wafer by a mercury-vapor lamp, which exposure method is capable, at a low cost, of minimizing the gradual decrease of the quantity of light radiated by the mercury-vapor lamp and also effecting exposure, which is performed repeatedly at a short time interval, stably over a long period of time.

In one aspect of this invention, there is accordingly provided a method for exposing, through a pattern mask, small sections of a semiconductor wafer successively to light radiated from a mercury-vapor lamp in high-level steps, during each of which the power consumption of the mercury-vapor lamp is at a high level, by continuously lighting the mercury-vapor lamp and repeatedly alternating each of the high-level steps and a low-level step during which the power consumption of the mercury-vapor lamp is at a low level, in which method the high-level step is repeated while gradually increasing the power consumption of the mercury-vapor lamp with the passage of the lit time of the mercury-vapor lamp so as to compensate gradual reduction of the quantity of light to be radiated by the mercury-vapor lamp.

According to the exposure method of this invention, the mercury-vapor lamp is lit at a low power consumption level while the light radiated from the mercury-vapor lamp is not used for exposure. It is thus possible to reduce, to a significant extent, the electricity to be wasted by the mercury-vapor lamp and at the same time, to avoid possible damages to the shutter due to its overheating.

The above and other objects, features and advantages of the present invention will become apparent from the following description and the appended claims, taken in conjunction with the accompanying drawings.

In the accompanying drawings:

Figure 1 is a simplified schematic illustration of one example of an exposure system;

Figure 2 is a graphic representation showing one example of the waveform of power consumption of a mercury-vapor lamp, which waveform varies due to the repetition of a high-level step and a low-level step;

Figure 3 is a fragmentary plan view of a semiconductor wafer, illustrating some of the sections to be exposed;

Figure 4 is a diagram showing how the power consumption of the mercury-vapor lamp is gradually increased in steps of the high energy consumption level along the passage of the lit time of the mercury-vapor lamp;

Figure 5 is a schematic illustration of one example of mercury-vapor lamps; and

Figure 6 is an enlarged fragmentary schematic illustration of the mercury-vapor lamp depicted in Figure 5.

The invention will hereinafter by described in detail with reference to the accompanying drawings.

For printing a pattern image by ultraviolet rays in such a manner as mentioned above, there is employed an exposure system having such an optical light-focusing and projection system as depicted for example in Figure 1. In Figure 1, numeral 1 indicates a short-arc mercury-vapor lamp which is an exposing light source. This short-arc mercury-vapor lamp 1 is installed at such a position that its arc is located on the focal point of a light-focusing mirror 5. Light L, which has been given off from the short-arc mercury-vapor lamp 1, is focused by the light-focusing mirror 5, and is then projected onto a photomask 11 bearing a circuit pattern image thereon by way of a first plane mirror 6, integrator 8, second plane mirror 7 and condenser lens 10. Light, which has been transmitted through the photomask 11, is projected via a reducing lens 12 onto a semiconductor wafer 2 supported in place on a susceptor (not shown) and bearing a photoresist film made of an ultraviolet ray sensitive resin and formed on the upper surface of the semiconductor wafer 2, thereby to print on the semiconductor wafer 2 a circuit pattern image corresponding to the photomask 11 but reduced in size with a reduction ratio of 1/10-1/5. Designated by numeral 4 is a shutter, whereas numeral 9 indicates a filter.

In the present invention, a semiconductor wafer is exposed in the following manner. In the system shown in Figure 1, electric power is continuously fed to a mercury-vapor lamp 1 built in a light-focusing mirror 5, so that the mercury-vapor lamp 1 is lit continuously. While maintaining the above lighting state, the electric power to be fed to the mercury-vapor lamp 1 is then controlled by an operation control circuit 3 so that the electric power takes the basic waveform illustrated by way of example in Figure 2. Accordingly the power consumption level of the mercury-vapor lamp 1 is alternated periodically and repeatedly between a high level, namely, Step A during which the power consumption of the mercury-vapor lamp 1 is of such a level as about 1.3 -2.5 times the rated power consumption of the mercury-vapor lamp 1, and a low level, namely, Step B during which the power consumption of the mercury-vapor lamp 1 is of a level equal or close to its rated power consumption. In Step A of the high power consumption level, a shutter 4 is opened and then closed so as to cause the light radiated from the mercury-vapor lamp 1 to expose a small section of a semiconductor wafer 2 through a photomask 11 for a constant time period, which small section is placed at an exposing position.

The extent of exposure may be controlled to a prescribed desired level on the exposed surface of the

semiconductor wafer 2 by setting the opening time of the shutter 4 suitably. In other words, the extent of exposure may be controlled by holding the shutter 4 in its opened position while the mercury-vapor lamp 1 is lit in Step A in which the power consumption of the mercury-vapor lamp 1 is at the high level. Then, after closing the shutter 4, the mercury-vapor lamp 1 is lit in Step B in which its power consumption is at the low level. During Step B, the shutter is kept closed.

The repeated alternation of Step A of the high level and Step B of the low level is carried out in synchronization with the manner of the stepwise shifting of the semiconductor wafer 2. Namely, as shown in Figure 3, the semiconductor wafer 2 is supposed to be divided into a number of minute sections P arranged in rows and columns. These minute sections P are then shifted stepwise one after another successively to the exposure position in the exposure system, where they are exposed one after another successively while held briefly at a standstill there. One exposure operation is completed after the opening and closing action of the shutter 4 while the mercury-vapor lamp 1 is lit in Step A, thereby printing a pattern image on one of the minute sections P of the semiconductor wafer 2. The wafer 2 is shifted stepwise while the shutter 4 is closed, so that another minute section P, which is to be exposed next, reaches the exposure position. Exposure is then repeated in the same manner so as to complete the exposure of all minute sections P arranged on the semiconductor wafer.

In the above manner, the mercury-vapor lamp 1 is lit while continuously and repeatedly alternating Step A of the high power consumption level and Step B of the low power consumption level. The opening and closing operation of the shutter 4 and the stepwise shifting position of the semiconductor wafer 2 are controlled in association with Step A and Step B. The time period Ta of each Step A of the high power consumption level may be set constant, for example within the range of from 100 msec. to 1000 msec., whereas the time periods Tb of Steps B of the low power consumption level may be the same or different and may range for example from 100 msec. to 1000 msec. In order to compensate gradual reduction of the quantity of light to be radiated along the passage of time in Steps A, Step A is repeated while increasing the power consumption little by little with the passage of time. The exposure of the semiconductor wafer is carried out in the above-described manner.

Here, it should be borne in mind that the manner of the gradual increase of the power consumption in the Steps A of the high power consumption level is not necessarily limited to any particular embodiment. The power consumption level may vary depending on the inherent characteristics of each mercury-vapor lamp to be employed. Specifically speaking, a power curve which increases along the passage of time to compensate gradual reduction of the quantity of light to be radiated with the passage of time is established on the basis of experiences for Steps A. It is possible to use, in accordance with the thus-established power curve, means for controlling the power consumption of the mercury-vapor lamp in Steps A. Alternatively, it is also feasible to employ means for measuring by a photosensor the quantity of light radiated to the semiconductor wafer, and then controlling the power consumption of the mercury-vapor lamp in each Step A by means of an operation control circuit 3 in accordance with the degree of reduction in light quantity relative to the initial light quantity. In some specific embodiments of this invention, the time-dependent variation of the power consumption in Steps A may take, macroscopically seen, the form of such a linear variation as shown for example in Figure 4.

It is unnecessary to change the power consumption in each of the Steps B of the low energy consumption level, if the power consumption is of a level equal or close to the rated power consumption of the mercury-vapor lamp.

In the practice of the method of this invention, it is possible to use, as the operation control circuit 3 for the lighting of the mercury-vapor lamp 1, a circuit conventionally known as means for effecting such power control, as is, or in a partly-modified form.

Figure 5 is a schematic illustration showing one example of a short-arc mercury-vapor lamp 1 to be assembled as an exposing light source in an exposure system useful in the practice of one embodiment of this invention. In Figure 5, numeral 101 indicates an envelope made of silica glass, which is equipped at both end portions thereof with bases 102A, 102B respectively. Designated at numeral 103, 104 are respectively an anode-supporting stem and cathode-supporting stem. An anode 105 is mounted on the tip of the anode-supporting stem 103, whereas a cathode 106 is fixedly attached to the tip of the cathode-supporting stem 104. The anode 105 and cathode 106 are disposed in a face-to-face relation, centrally, in the interior of the envelope 101. As illustrated on the enlarged scale in Figure 6, the anode 105 is formed of a base portion 51 having a large diameter column-like shape and a truncated conical tip portion or frusto-conical tip portion 53 extending frontwardly and inwardly from the base portion 51 and terminating in a planar tip surface 52. The cathode 106 is formed of a base portion 61 and a cone-like tip portion 62.

An illustrative specification of such a short-arc mercury-vapor lamp 1 is as follow:

Specification

	Rated power consumption	500 W (50V,10A)
	Anode 105:	
	Outer diameter D_1 of the base portion 51	4.0 mm
	Diameter D_2 of the tip surface 52	2.0 mm
	Opening angle α of the tip portion 53	90 degrees
	Cathode 106:	
	Outer diameter D_3 of the base portion 61	2.0 mm
	Interelectrode distance	3.0 mm
	Pressure in the envelope while the lamp is turned on	about 13 atms.

Using a semiconductor wafer exposure system equipped with a mercury-vapor lamp of the above structure built in as an exposing light source, pattern exposure was conducted on a silicon semiconductor wafer in accordance with the stepwise exposure method while controlling the lighting of the mercury-vapor lamp under the following conditions.

Step A
Time interval Ta: 400 msec.
Power consumption: Increased substantially in a linear pattern, starting at 750 W and upon an elapsed time of 600 hours, ending up at 1 KW.

Step B
Time interval Tb: 400 msec.
Power consumption: Maintained constant at 500 W.

Under the above conditions, it was possible to achieve the same exposure results as the initial exposure results even after an elapsed time of 600 hours.

The method of this invention can bring about the following advantageous effects:

(1) The mercury-vapor lamp is lit at a low power consumption level while the light radiated from the mercury-vapor lamp is not used for exposure. It is thus possible to reduce, to a significant extent, the electricity to be wasted by the mercury-vapor lamp and, at the same time, to avoid possible damage to the shutter due to its overheating. In a preferred embodiment, the mercury-vapor lamp may be lit at its rated power consumption level in the steps of the low power consumption level, and its power consumption is increased in the steps of the high power consumption level. Thus, the degree of exposure can be adjusted as needed or desired. Accordingly, the exposure of semiconductor wafers can be suitably carried out with a small mercury-vapor lamp. As a result, the exposure system does not require too much space for its installation, thereby making it possible to lower the cost required for the maintenance of a clean room or the like in which the exposure system is installed and, consequently, to lower the fabrication cost of the semiconductor devices significantly.

(2) The steps of the high power consumption level are repeated while increasing the power consumption of the mercury-vapor lamp little by little during the lit time of the mercury-vapor lamp. The exposure of the semiconductor wafer is effected in the steps of such a high power consumption level. Even when the light transmittance of the envelope of the mercury-vapor lamp is decreased due to wearing of its electrodes and deposition of the electrode-forming material on the envelole, the reduced quantity of radiated light can be compensated by the increase in the power consumption. It is thus possible to keep the quantity of light radiated from the mercury-vapor lamp even in later stages of the steps of the high power consumption level still at the same level as its initial light quantity level. As a result, semiconductor wafers may be expos d with a stable quantity level of radiated light over a long period of time.

(3) The control of the degree of exposure is eff cted by means of a shutter. Since the time-depend nt reduction of the quantity of light to be radiated from the mercury-vapor lamp is compensated, as mentioned above, by increasing the power consumption of the mercury-vapor lamp along the passage of time in Steps A f the high power consumption level, the opening and closing control of the shutter may be kept constant. Therefore, it is unnecessary to make such a difficult control as changing the opening time of the shutter by a very short period of time. Hence, the exposure can be repeated at a high speed and also stably.

Having now fully described the invention, it will be apparent to one of ordinary skill in the art that many changes and modifications can be made thereto without departing from the spirit or scope of the invention as set forth herein.

CLAIMS

1. A method for exposing, through a pattern mask, successive small sections of a semiconductor wafer to light radiated from a mercury-vapor lamp in high-level steps, during each of which steps the power consumption of the mercury-vapor lamp is at a high level, by continuously lighting the mercury-vapor lamp and repeatedly alternating the high-level steps with low-level steps during which the power consumption of the mercury-vapor lamp is at a low level, characterised in that the high-level steps are repeated while gradually increasing the power consumption of the mercury-vapor lamp with the passage of the lit time of the mercury-vapor lamp so as to compensate gradual reduction of the quantity of light radiated by the mercury-vapor lamp.
2. A method as claimed in Claim 1, wherein a shutter is opened and then closed only once during the period of each of said high-level steps so as to expose the corresponding one of the small sections of the semiconductor wafer at an exposure position.
3. A method as claimed in Claim 2, wherein the opening time period of the shutter in each of said high-level steps is constant.
4. A method as claimed in Claim 2 or Claim 3, wherein the opening time period of said shutter is from 100 msec. to 1000 msec.
5. A method as claimed in any of Claims 2 to 4, wherein said semiconductor wafer is shifted stepwise to place the next small section at the exposure position while said shutter is closed.
6. A method as claimed in any of Claims 2 to 5, wherein said shutter is closed for a time period of from 100 msec. to 1000 msec.
7. A method as claimed in any preceding Claim, wherein the level of the power consumption in each of said low-level steps is substantially equal to the rated power consumption of the mercury-vapor lamp, and the level of the power consumption in each of said high-level steps is from 1.3 to 2.5 times the rated power consumption of the mercury-vapor lamp.
8. A method for exposing semiconductor wafers to a mercury-vapor lamp, substantially as hereinbefore described with reference to the accompanying drawings.
9. Semiconductor wafers, whenever produced by a process including an exposure method according to any preceding Claim.
10. The features herein described, or their equivalents, in any patentably novel selection.

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